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BASIC SYSTEMS THEORY AND CONCEPTS UNDERLYING CONSTRUCTION OF THE KOREAN SIMULATION MODEL WITH IMPLICATIONS FOR FURTHER WORK

by

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Introduction

Due to an unfortunate lack of consistency in terminology these days in discussing "systems"--their organization, properties, functions, design and management we have, potentially at least, virtually unlimited freedom in choosing directions for this discussion to take. We could go in many different directions ranging from a philosophical discussion of values to a highly mathematical treatment of system structure and interconnection and someone would be convinced that our content was consistent with the title above. It's therefore important to state clearly at the outset what we mean by "Basic Systems Theory and Concepts" and how all this relates to development problems in Korea and elsewhere.

Fundamentally we are talking about a problem solving philosophy or approach and a collection of quantitative and non-quantitative methods for implementing the approach. Elsewhere, this has been called "System Design" (Asimow, 1962) and "The Systems Approach" (Churchman, 1968). We have contributed to the confusion in terminology by calling this the "System Simulation Approach" in our work.

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What are some of the key attributes of this approach? We'll summarize some of the more important ones here and elaborate later in discussion that relates specifically to the Korean experience. Firstly, the approach has as its overall objective the efficient satisfaction of human needs. Since real-world needs are usually interrelated in complex ways, the approach devotes considerable attention to the appropriate definition of "needs." A corollary to this statement is that the approach attempts to consider undesired consequences produced while satisfying needs--the effect of attaining one set of values on the level of attainment of another value set. Secondly, the approach attempts to consider all factors that in one way or another significantly affect the satisfaction of the identified needs. It therefore mobilizes a multi-disciplinary attack on the problem and involves a team composed of disciplinary generalists and specialists. A third key attribute of the approach is that it makes use of models and other quantitative methods _when it is prudent in light of problem-solving objectives to do so_. Models are designed to solve problems and are not an end in themselves. The kinds of models constructed are determined by the needs of the problem to be solved. (Anyone involved in model building can testify to the difficulty involved in being objective about this. It is _very_ easy to let models become an end in themselves.) In this approach models are meant to be one of possibly several inputs to the decision-making process. Other inputs provided by the approach may include special papers and reports dealing with non-quantifiable factors and _qualitative_ analyses of decision alternatives.

Before going into a more detailed discussion of the approach as it was applied in Korea, a disclaimer or two are in order. We do not consider that our work in Korea exemplifies adequate adherence to the principles briefly introduced above. There are several reasons for this It is impossible to consider "all factors that in one way or another significantly affect the satisfaction of identified needs" within tight time, budgetary and personnel constraints. Judgments must be made on priority areas for investigation and attention given to these. Further, as a team we had gaps in our objectivity and our ability to deal adequately with the entire broad spectrum of disciplinary issues relevant to rural development in Korea. The principles outlined were important, however, in that they provided us with overall guidelines in seeking solutions to practical problems. It is fair to say that "The Systems Approach" had a significant impact on the Korean Agricultural Sector Study--its content and implementation. We explore this in more detail in the next section.

The Korean Agricultural Sector Study As An Application of the "Systems Approach"

We will begin by examining the scope of the Korean Agricultural Sector Study and its objectives in more detail. A primary motivation for the study was to seek ways of better meeting the needs of rural people. These needs included increased income, equitable income distribution, improved health nutrition and other measures of quality of life. (Only income, regional income distribution and nutrition were dealt with explicitly in the original version of the computer model.) It was also necessary, however, to consider needs of other groups and institutions of Korean society as they related to and/or conflicted with these rural needs. In this vein the KASS study included factors such as urban nutritional levels, urban food price indices, imports, exports, foreign exchange deficits and the costs of governmental rural development programs. All of these latter factors were explicitly included in the original computer model or in related analysis.

To adequately deal with these needs (trade-offs among them and the effects of policy actions upon the levels of their satisfaction) the KASS study as a whole (and the computer model) had to consider the production, marketing, and consumption of a number of agricultural commodities (18) on a region-specific basis. Fisheries was included in the analysis to the extent necessary to estimate contributions to human nutrition, particularly protein. Since important decision-making criteria included benefits attainable on a per-capita basis from alternative policy actions, the analysis necessarily included models of the age/sex distribution of rural and urban populations over time as affected by birth, death and migration rates. (Age/sex classifications become necessary to deal with questions of nutritional needs, rural labor supply and composition of migration streams).

The real-world problem of satisfying a diverse array of, generally competitive, needs required consideration of a broad array of policy instruments for attaining objectives. These included price policies; research programs to generate improved agricultural technology; extension programs; programs to expand the available land base; irrigation, drainage and other programs to improve land productivity; improvement of rural infrastructure and population control. To be meaningful in the given problem setting; research, extension, and other programs had to be considered on a commodity-specific basis. All these policy variables, with the exception of investments in rural infrastructure were included, at least rudimentarily, in the original KASS computer model. Infrastructure was dealt with in an auxiliary project working paper.

The importance of institutions and political factors in the attainment of rural development objectives made it necessary to devote substantial study to these areas. Auxiliary working papers were developed which considered organization of the (then) Ministry of Agriculture and Forestry and the important National Agricultural Cooperative Federation. While they did not provide inputs to formal computer models, these studies provided a number of recommendations for significantly improving the performance of the economy in meeting the array of extant needs.

To summarize, the Korean Agricultural Sector Analysis employed an organized problem-solving process (the "Systems Approach" or the same thing called by another name) to:

- Determine the appropriate system (problem) boundaries including specification of what is endogenous and what is exogenous
- Identify the relevant real-world needs to be considered
- Identify the set of criteria (rural income/capita by region, rural/urban calories/protein per capita, agricultural trade balance, etc.) to be used to evaluate the consequences of alternative policy actions in satisfying the various needs.
- Identify the set of decision variables and issues which are important to consider in formulating alternative means for attaining objectives. (Organizational and institutional factors, prices to be regulated, stocks and flows to be managed in price control, tax policies, time and commodity specific investments in biological research and extension; land and water development projects, etc.)

These areas of activity, conducted in a "goal seeking" repetitive framework over a period of several months, led to the conceptual specification of the original version of the KASS computer model, and importantly, also led to specification of supporting studies dealing with significant problem related issues such as governmental institutions and organization and rural infrastructure which could not be feasibly modeled at the time. This process of "problem definition" is necessarily a continuing one.

The changing problem setting and environment force continual review and updating of problem-solving objectives and strategies for attaining objectives.

Recent developments provide a dramatic example of this. Since the original course for the KASS project was charted in 1971, world grain prices have increased sharply, grain reserves in exporting countries have declined markedly, chemical fertilizer has become scarce and expensive, and the ability of the Korean economy to finance needed imports has been significantly reduced. A specter of near term, large scale, food shortages now hangs over Korea and most of heavily populated Asia. It would seem that the whole focus of the project activities, modeling and otherwise, must be rethought in light of these developments. This includes reexamination of the array of policy instruments to be used in attaining these goals. KASS modeling efforts and other non-modeling activities (such as the new KAPP project) should be reviewed and revised to ensure that they are consistent with the nature of problems Korea is now facing. A reordering of project priorities will probably be necessary. It may well be that new sub-studies, qualitative as well as quantitative will be needed and may, in certain cases, replace those that are ongoing or planned.

Some important specific areas for investigation or reinvestigation appear clear at this time. While only a beginning toward the reformulation above, it may be well to list some of these.

> A new study to evaluate means of increasing emergency reserve stocks of grain at consumer, middleman and government levels.
>
> A reassessment of the goals for biological research. Those proposed in the 1972 Agricultural Investment Study [7] and included in the new AID investment loan may no longer be appropriate, particularly in light of potential fertilizer and price restrictions.

- A reassessment of the needs for agricultural mechanization (by type and intensity of introduction) in light of energy availability and a potential decline in rural/urban migration rates. The conclusions and recommendations contained in 1972 Exotech Mechinazation study [4] will require revision.

- A reassessment of previous KASS recommendations on commodity-specific extension programs.

- A review of current livestock expansion programs.

Some Technical Characteristics of the Model and Modeling Approach

At this point we must leave the broader thrust of the work in Korea and focus upon the model building activities and specifically upon technical features of the model and modeling approach. Our discussion will go beyond the original KASS model and embrace the model building in its entirity as it moves beyond the "Model T" version used as an input to the KASS report at the end of the first year of the project. We will discuss features of the model and modeling approach that are germain or are likely to become so as institutionalized models are applied and updated over time. We organize our remarks in three parts: characteristics of the models per-se, procedures for model testing and evaluation, and a brief description of how the models are or can be employed as part of the decision-making process.

Characteristics of the Korean Models

One important characteristic of the Korean models is that they are dynamic. Given the set of initial values for variables such as prices, levels of various stocks of goods, capital, people, etc. (the state variables of the system) and given values for exogenous variables (e.g., projections of world prices) the models compute the <u>time paths</u> of all model variables. The models are usually programmed so that they are recursive in time. That is the models generate time paths by computing all variables for successive points in time separated by a selected time interval. This time interval may vary depending upon the time frame of interest in the problem setting and upon some technical factors time doesn't permit us to delve into. In many cases variables are computed at yearly intervals. Included here are variables such as region-specific agricultural per capita incomes and commodity specific foreign exchange earnings/deficits. In these cases yearly model results are adequate for decision making purposes. On the other hand, certain variables associated with the grain management program model are computed at much finer time increments (currently .025 years). This is done to provide for realistic simulation of seasonal farm sales, prices, government purchases, sales, and stocks, etc. and to provide needed information at these fine time intervals.

A second characteristic of the Korean models is their incorporation of <u>explicit models of physical, economic, biological and social processes</u> that are part of the interactive structure that makes the real world behave as it does. Examples are models of crop production processes (annual and perrenial), decision-making processes, human demography, generation of government grain warehouse capacity, transportation lags in grain importation, and social diffusion of agricultural production technology. Simulation experience in many areas has shown that faithful representation of system "structure" is essential in capturing essential dynamic characteristics of complex systems. (See for example Forrester [5])

A model characteristic closely related to the above is the incorpora tion of goal-seeking (cybernetic) mechanisms where they are important in regulating real-world stocks and flows. This is another aspect of system "structure" mentioned above. A primitive example of this is the mechanism in the original computer model that regulates farm storage so that subsistence farm families maintain stocks which will last until the output of the next harvest. The grain management program model includes a number of cybernetic mechanisms which regulate inventory capacity, commodity specific stock levels, and importantly, commodity prices. The "control laws" that specify the corrective signals which provide regulation are often important policy-determined variables that have a significant effect upon system performance. Control theory [3], a discipline that deals with the design of control laws to attain specified objectives, has found considerable application in the Korean models to date and will find increasing use as complex government grain price regulation problems are addressed further.

As an aside, there are other useful applications of modern control theory in the process of modeling large socio-economic systems. Of particular interest is work in the area of estimating unknown parameters in dynamic systems [6]--work that complements the econometric methods normally used to estimate model parameters. Out of this literature has come recursive estimation techniques (Kahlmanfiltering being one of them) that permit updating of parameter estimates on the basis of <u>a single new set of data observations</u> (without starting from scratch each time an improved set of estimates is required). The implications of this for the information systems that supply models with data are significant and should be explored further.

Another characteristic of the Korean models to be discussed here is their incorporation of maximizing models when it appears appropriate in the problem-solving context to do so. A case in point is the use of the linear programming model to simulate farm resource allocation. The hypothesis was that this is a reasonable model to describe farmer responses to certain government programs and policies. The use of a maximizing model is under consideration for inclusion at some point in the simulation of the behavior of middlemen in buying, selling and storing grain. Some of the results from optimal control theory [8] and operations research [9] apply here where the object is to maximize a criterion over the time paths of a dynamic system. Economic theory assuming maximizing farmer behavior is being employed in new model developments to determine variable resource allocations to factors of production.

A final characteristic of the Korean models to be discussed here is their use of the "building block" approach. The models include a number of function-oriented building blocks. For example, one general purpose crop production building block was used 36 times in the original computer model to simulate annual crop production for 12 commodities in 3 regions of the country. One human population model was used to simulate rural and urban populations over time. There are several advantages in taking this approach. One is a saving of time and money in model development. A second is increased flexibility in expanding or contracting the scope of a model to include more or less commodities, regions, etc. Another is that this model-building approach ties in nicely with the concept of a library of generalized modeling components. More will be said about this "software library" later.

Model Testing and Evaluation

We turn our attention briefly now to consider model testing and evaluation procedures used or likely to be used in the Korean work.

Once a model has come to the stage of development where serious programming errors have been eliminated and results appear to be logically consistent it is useful to carry out "sensitivity analysis" by varying selected model parameters individually or in logical groupings in successive computer runs. These tests serve several purposes. They can identify key model parameters that require better estimates. This can lead to priorities and economies in the acquisition of more/better data. The sensitivity tests can also provide additional evidence on the internal consistency and reasonableness of the model. Such tests often uncover defects in the model that require modification. Sensitivity analysis conducted after models have reached an advanced state of development can be useful in providing information to decision makers. For example, sensitivity analysis carried out on crop yield parameters can provide useful information for helping establish goals for biological research.

A second kind of model test useful in the model development process is what we'll call "historical" or "time series" tracking. The objective here is to test the ability of the model to reproduce a part of the past history of the real world system under study. The ability of a model to do this is by no means proof of model validity. It is, however, additional evidence in support of use of the model as one input to the decision-making process. In certain cases, "historical tracking" can be used as a means of estimating values for model parameters which cannot be obtained suitably by other means. Here the idea is to find the set of unknown model parameter values that produces the "best" model fit to the historical data. A Ph.D. dissertation, supported by this project at MSU, is further developing automatic computer routines which can apply this technique to large scale (generally nonlinear) simulation models in a number of cases of practical interest. There is a need for substantially more historical tracking (and sensitivity analysis) in the Korean modeling effort.

Model Application

We now turn our attention briefly to the use of the Korean models in the decision-making process. The point has been made that in the Korean experience computer models are part of a larger "model" that involves decision makers, analysts and models in an interactive process. We wil not go into the details of this process here but suffice it to say that this interactive process can: 1) help decision makers determine what alternative goals can feasibly be attained given resource constraints and constraints imposed by the real world system structure, 2) help decision makers arrive at normative judgments concerning the specific set of values to seek (the models can do this by displaying feasible trade-offs among conflicting values) and 3) the models can help in determining efficient means of attaining goals which have been established. In cases where decision making issues can be meaningfully stated in terms of an optimization problem it is possible to operate the Korean models in an optimization mode to determine a decision strategy that will optimize the selected criterion. In fact, the techniques mentioned above being developed to automatically tune models to give a "best" fit to historical time series can also be used with little modification to solve this decision optimization problem.

A final point on model application: another kind of model test which may be desirable at some point in Korea is so-called Monte Carlo testing. In this case a series of simulation runs are made and a set of random values are assigned to random exogenous variables and to model parameters which are subject to uncertainty. (Random values are assigned using estimates of the expected standard errors in individual parameter values.) Series of runs are made for a number of alternative policies of interest to decision makers and statistics are computed for criteria of interest to decision makers for each alternative policy. These results give decision makers information on the range of outcomes that are possible under each alternative due to the uncertainty that exists in model data and due to random exogenous variables. They can also lead to the computation of confidence intervals for the outcomes of alternative policies. While computationally feasible, Monte Carlo runs for the entire sector model as it is now being developed. This sort of thing is much more likely to be useful for models or sub-models which use substantially less computer time. The grain management model is perhaps a good case in point.

Conclusions

We have taken a brief look at the problem-solving approach being employed in the Korean work and some of the characteristics and capabilities of the quantitative methods that are being employed to address real world problems. (Not enough has been said, however, about the limitations of the quantitative methods, the problems of reliable data, aggregation problems, gaps in theory, etc.) We have seen that the problem setting has changed radically in the past year and that this necessitates a major reevaluation by Koreans of the directions their rural development efforts are taking. In order to meaningfully address these changing needs this also, clearly, requires a major reevaluation of the directions this project is taking. At the least this will mean model modifications to include additional factors which have recently taken on much greater importance (such as incorporation of emergency reserve food stocks at various levels) or it may mean a major revision of priorities within the project which leads to aborting some activities and starting up others. In any event the needs of the problem should play a major role in determining the quantitative and qualitative directions the project takes. I'm convinced on the basis of 10 or more years experience in working with this problem-solving approach that appropriate models can play a useful and important role in addressing the new problems Korea faces. At this point, however, I'm far from clear on what precisely "appropriate" means.

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